Institutionen för datavetenskap
Department of Computer and Information Science

Examensarbete

Optimizing Mobile Phone Free Fall Drop Test Equipment – Precision, Repeatability, and Time Efficiency

av

Boris Asadanin

LIU-IDA/LITH-EX-A--08/060--SE

2009-01-09

Linköpings universitet

Linköpings universitet
SE-581 83 Linköping, Sweden

Linköpings universitet
581 83 Linköping

Examensarbete

Optimizing Mobile Phone Free Fall Drop Test Equipment – Precision, Repeatability, and Time Efficiency

av

Boris Asadanin

LIU-IDA/LITH-EX-A--08/060--SE

2009-01-08

Handledare: Anders Larsson

Examinator: Erik Larsson

Abstract

Free fall drop testing is an important part of the development of commercial electronic components and devices. In the process of optimizing the quality of their entire product range, Sony Ericsson Mobile Communications AB have decided to review their free fall drop test equipment with the goal of increasing the precision, repeatability, and time efficiency of their drop test applications. In regard to the free fall drop test principle a robot system with management software, named Doris Drop Test System, is developed to meet these goals.

As the amount of related work for this application is as minimal as the timeframes for this project, the development process is empirical and entrepreneurial with engineering skills as the governing line of work. Combining the competence from fields such as mechanics, electronics and product development, reaching the goals is successful enabling the identifying of two different drop methods – Impact Position and Drop Position. Increasing the repeatability from approximately 10% to 85% enables anyone at any time to perform the exact mobile phone drop test. By reaching a precision of up to 100%, performing free fall drop tests aiming for testing specific mobile phone parts, optimizes the development process by faster detection of mechanical weaknesses. Achieving these results in parallel with increasing the throughput by shortening the testing time, has proven the success of the Doris Drop Test System.

Achnowledgements

This master thesis work is a product of several highly competent engineers and other people that have put invaluable contributions throughout the entire project. I would like to take the opportunity to thank all the people involved in developing the Doris Drop Test System.

Sony Ericsson, Kista
Stefan Persson
Lennart Bjurling
Osvaldo Veitia
Sony Ericsson Test Team Kista
Sony Ericsson Mechanics Department Kista

Linköping Institute of Technology
Anders Larsson, Instructor
Erik Larsson, Examiner

Bozzanova Design
Marc Manchec

All vendors involved

Boris Asadanin
Linköping Institute of Technology

1 Introduction

1.1 Background

This section gives a brief background of Sony Ericsson Mobil Communications AB and their mobile phone testing.

1.1.1 Sony Ericsson Mobile Communications AB

Sony Ericsson Mobile Communications AB is a joint venture established in 2001 by Sony Corporation and Telefonaktiebolaget Ericsson.[1] "*The stated reason for this venture is to combine Sony's consumer electronics expertise with Ericsson's technological leadership in the communications sector. Both companies have stopped making their own mobile phones.*"[2] Sony Ericsson Mobile Communication AB (below referred to as Sony Ericsson) has research & development teams in Sweden, Japan, China, Canada, the Netherlands, the United States, India and the United Kingdom. Sony Ericsson in Kista is developing the smartphone part of the company's product range. Recent phone releases include M600i, W950i, W960i, P990 and the most recent P1 model.

1.1.2 Mobile Phone Testing

During mobile phone development every mobile phone model must pass through a series of tests that are specified in the Test Plan. The Test Plan, which is global and shared among every Sony Ericsson test site, describes every specific test comprehensively. The tests can be divided into two major categories, hardware tests and software tests. The free fall drop test is an important part of the hardware tests. The free fall drop tests are used for detecting construction weaknesses, which are reported and corrected during the development of later prototype series.

There are several types of drop testing. This thesis regards only free fall drop tests. Other types of tests, such as constrained drop tests, different types of simulated drop tests etc, are described and discussed in chapter 4.

1.2 Problem

In order to optimize the free fall drop tests Sony Ericsson needs an enhanced mechanic equipment that is able to drop mobile phones much more accurately than the equipment used for the moment. Not being able to repeat the drop cases that caused the damage affects the development negatively by not discerning whether a corrective measurement is successful. Additionally, as Sony Ericsson in Kista grows and is developing more products the throughput of the drop test has to increase.

Dropping mobile phones more accurately, in a more repetitive manner, and increasing the throughput of the tests, correspond to the goals of this project – precision, repeatability and time efficiency.

---

[1] Sony Ericsson Communications AB, *Mission,* retrieved 6 July 2008, <http://www.sonyericsson.com/cws/companyandpress/aboutus/mission?cc=gb&lc=en>

[2] Wikipedia, *Sony Ericsson,* retrieved 6 July 2008, < http://en.wikipedia.org/wiki/Sony_ericsson>

1.3 Purpose

The purpose of the project is to enhance the precision, repeatability and time efficiency of the drop test part of the development process. This will make the test results more reliable since the mobile phones can be dropped in a more controllable way. More controlled drops will render into a more precise analysis of weak points thus making Sony Ericsson's product range physically enhanced. Repeatability and time efficiency will also result in a faster and therefore cheaper testing process. The goals and their impact are described in detail in the following section.

1.4 Goals

The goal of the project is to develop a mechanical system that has the capacity to make the free fall drop tests more efficient and reliable. The goals are divided into the following three areas:

- Precision
- Repeatability
- Time efficiency

1.4.1 Precision

The free fall drop test equipment must drop devices very accurately in order to measure the strength of every part of a mobile phone's surface. The equipment must therefore be able to drop devices in every possible angle in order to achieve the right device impact position. The precision goals are closely related to the repeatability goals.

1.4.2 Repeatability

The free fall drop test equipment must be able to repeat every separate drop accurately to be able to verify that corrective actions are successful between the different prototype series. The repeatability must be independent of who is performing the tests and when the tests are executed.

1.4.3 Time efficiency

There are several areas where the mechanical drop test equipment can be made more time efficient. One of these areas is the time it takes to balance the phone before a drop. Another area is the time it takes to change drop height. These are the most time consuming parts of performing drop tests, and should be minimized. This of course has to be done without lowering the standards of precision, repeatability and most importantly; safety for the Sony Ericsson personnel.

1.5 Prerequisites

Previous studies made by Sony Ericsson personnel confirm that a robot is the best suited equipment for accurate free fall drop testing. In order to reach different drop heights the robot should be placed upon a lifting column. A large industrial robot would of course also reach higher drop positions but the shortcoming of a large robot is its price, precision and its limited vertical range. Using a large industrial robot to manage devices not exceeding 200 grams would also be unnecessary.

The robot's precision and ability to reach all different drop positions results in two different types of drops that Sony Ericsson personnel have identified beforehand. Later in the project those types are named Drop Position and Impact Position drops. The difference is the orientation of a device during drops. Drop Position drops only consider the devices' orientation in the grip releasing moment (ie. when the gripper releases the phone) without considering how the device is orientated upon impact. Impact Position drops focuses only on the devices orientation upon impact without considering the devices' orientation in the grip releasing moment. A well known fact among the drop test personnel is that a dropped device always rotates a few degrees during the fall, changing its orientation until impact. Trimming the drop position, i.e. changing the mobile phone's gripped orientation before releasing it, compensates for the rotation thus achieving desired impact position. Therefore, trimming the drop position is one of the main objectives of the project.

Besides the trimming of the robot, another key requirement for the project is to develop software for managing the robot and all different types of drops. The software that should be installed on a PC with the Windows XP platform installed, must manage the different entities that free fall drop tests use. The entities are:

- Project – referring to a specific phone model
- Scenario – a pre defined series of drops
- Drop Case – a drop case defining drop positions etc. Drop cases are covered in detail in chapter 2

Furthermore, the managing software should save the different robot drop positions on a hard drive granting any member of the Sony Ericsson test department the ability to repeat the drop cases.

1.6 Delimitation

Many factors influencing the project make the delimitation rather complicated. However, the delimitation is important foremost because of the limited time frame for this project. Surely, several solutions would meet our goals but examining and studying them all would be too time consuming and is therefore beyond the scope of this project. The construction of Doris Drop Test System is based upon studies made by Sony Ericsson personnel before the project start. The result of the studies entailed an idea of how the goals would be achieved mechanically. The mechanical equipment that should be used is a robot system with a pneumatic gripper for dropping mobile phones. Moreover, the robot system should be placed upon a lifting column in order to reach all different drop heights.

Further limitations of the project are described below:

- The drop test system must be able to drop mobile phones that are cuboid shaped with no moving parts. Other phone types like the Jack Knife, Clam Shell or Slide phone models do not have to be included in the project. Mobile phone models that have microphone lids are also excluded from the project. Hence all mobile phones tested during this project were cuboid shaped (M600i, W950i, W960i, P1).
- The drop test system is only required to drop mobile phones using the same pneumatic gripper and gripper extensions. Exchanging gripper extensions is not within the scope of this project. Since the time frame of the project is exceedingly narrow, the ability to drop mobile phone models of different dimension is not prioritized.
- The drop test system shall neither pick up dropped devices nor in any other way examine them. Dropped devices are only to be picked up by Sony Ericsson personnel.
- A mechanical system for free fall drop tests has to be developed. A robot with a pneumatic gripper is to grip the phone, move it to the right height, position, and orientation before releasing it. The drop test equipment has to be manageable from a PC software with the possibility of trimming and saving drop orientations.
- No specific consideration has to be taken to the air flow induced by free fall drop tests affecting the falling mobile phone. The possibility of trimming the drop positions should compensate for the rotation of the mobile phone during a drop.
- The PC software managing the drop test equipment has to fulfil the requirements of Sony Ericsson based on the Test Plan. This includes support for scenarios, projects, trimming and saving drops etc.

1.7 Disposition

This section gives an overview of this document and briefly declares the content of each chapter.

Chapter 2 – Drop Testing

This chapter gives an introduction and discussion of this work and of drop testing at Sony Ericsson. The chapter explains some techniques and terms used by Sony Ericsson. This chapter also contains a brief description of the current mobile phone drop test equipment and its drawbacks.

Chapter 3 – Doris Drop Test System

This chapter gives a detailed description of all parts of Doris Drop Test System and how it is designed to meet the goals specified in Section 1.4.

Chapter 4 – Related Work

This chapter gives a deeper understanding of techniques that are used in different applications of drop testing.

Chapter 5 – Developing Doris Drop Test System

This chapter discusses all but one part of the development process of Doris Drop Test System. The testing part is covered in chapter 6. Important design decisions are covered in this chapter.

Chapter 6 – Tests

This chapter gives a detailed description of all the different stages of testing Doris Drop Test System. It also includes the theoretical and practical investigations and tests from the initial stages of the project.

Chapter 7 – Experimental Results

In this chapter an empirical comparison between the old drop test system and Doris Drop Test System is made. It is focused on the three goals: precision, repeatability, and time efficiency.

Chapter 8 – Drawbacks and Enhancement Possibilities

This chapter gives a discussion about Doris Drop Test System, its usage and its limitations. Additionally some recommended changes are mentioned.

Chapter 9 – Conclusions

This chapter gives a final conclusion of the results achieved.

1.8 Confidentiality

As the Doris Drop Test System is used in regular production by Sony Ericsson, the details of the drop test equipment is required to be kept confidential. Specific details as the details of the Test Plan (how many times a mobile phone is dropped etc.), robot names, robot vendor etc. will be omitted due to the discretion of the Doris Drop Test System.

All rights of the Doris Management Software and the DROP Software are owned by Sony Ericsson. The code is therefore confidential.

Note that the confidential details omitted in this document are not indispensable for understanding the thesis work and its results.

2 Drop Testing

2.1 Introduction

The free fall drop tests are an important part in the development of mobile phones. They are done to inspect the physical weaknesses of the mobile phone, and by correcting these achieve the most qualitative mobile phone for customers. This introduction gives a brief explanation of how these free fall drop tests are done and what equipment is used.

The shape of every mobile phone model can be approximated by a cuboid with six surfaces, twelve edges and eight corners. The Test Plan specifies that a device must be dropped on every one of these 26 different surfaces, edges and corners. Every drop is filmed with a high speed camera. The movie clips are then evaluated by Sony Ericsson's mechanics department and compared with physical damages caused on each tested device in order to get a complete awareness of construction weaknesses. This enables the right corrective measures to be taken. Being able to drop mobile phones accurately also increases the accuracy in determining if a corrective action is successful.

During a mobile phone development process different prototype releases are made a few months apart. The tests are carried out separately on mobile phones from all prototype series. This causes the same tests to be carried out on different times and by different persons during the development process. Using the old drop test equipment, the main consequence is that it is extremely difficult to remember, or in some way, to save the exact set up and configuration of the tests in order to repeat them. The reason for this is mainly because the mobile phones are placed manually onto the drop test equipment. This damages the ability to determine if corrective actions are successful between the different prototype series.

The tests are carried out by the test team and by members of the mechanics department. Regular tests are executed mainly by the test personnel but specific tests (separate parts or specific impact angles) can be carried out by any member of the mechanics department.

2.1.1 Drop Cases

The amount of drop cases in the standard set is 26 since a rectangular cuboid has 26 surfaces, edges and corners. Every drop case has a name that is formed from the surrounding surfaces in regard to the impact point. There are predefined names of the surfaces of the phone, Front, Back, Left, Right, Top and Bottom, where Front is the side of the main display on a mobile phone.

The drop cases are grouped in scenarios specified in the Test Plan. The scenarios consist of a series of drop tests. The scenarios will not be described in more detail since the Test Plan is confidential.

2.2 The Old Free Fall Drop Test Equipment

The old drop test equipment consists of a ramp upon which a device is manually placed in the right drop position. The ramp is pulled down underneath the device which falls onto a special kind of concrete brick (specified in the Test Plan). The ramp is pulled down with a rubber cord which causes the ramp to accelerate faster than the gravitational force. To be able to achieve all possible drop positions an adjustable arm is placed above the ramp and is used for balancing the device in its drop position. Aside from the easiest drop cases, front drop or back drop, the device must be tilted in some way to achieve the necessary drop position. The device is placed onto the ramp and balanced according to the desired drop position.

The release handle which triggers the ramp to be pulled down is also connected to the camera trigger which starts the camera shoot. The camera is able to capture more than 5000 pictures per second which has been more than enough to see a highly detailed picture of the impact. Sony Ericsson's camera has therefore been used for the Doris Drop Test System. Also, according to Goyal and Buratynski a minimum of 1000 frames/s is required to show the details of a drop impact[3], again, making the available camera fully sufficient.

2.3 Drawbacks with Old Free Fall Drop Test Equipment

The major drawbacks with the old free fall drop test equipment are precision and repeatability. Since a device is manually placed on top of the ramp it is placed differently each time, especially when different Sony Ericsson test personnel carries out the tests. Since the tests are carried out continuously during an entire phone development period the probability that drop cases are carried out differently and by different people increases. It is also next to impossible to save the exact set up of the tests.

The trimming is also very hard and time consuming to handle. It is easy to place a phone on its back or front on top of the horizontal ramp, but for corner drops it is harder to balance the device to the necessary drop position. The Sony Ericsson test personnel must manually adjust the balancing arm and then balance the device in the right drop position. This can also be very complicated and frustrating, especially after a few drops when a device is dented. The balancing problem not only causes great loss in time but also in precision and repeatability, not to mention temper.

[3] S. Goyal, E.K Buratynski, *Methods for Realistic Drop Testing*, The international Journal of Microcircuits and Electronic Packaging, Vol. 23, Number 1, 2000, p. 46.

3 Doris Drop Test System

The Doris Drop Test System consists of two parts – the hardware equipment and the software. The hardware is divided into the robot controller, the robot unit, the pneumatic gripper, the lifting column, the camera and the safety cage including the peripheral safety equipment. The software is divided into the Doris Management Software (PC software) and the DROP Software (robot controller software). The same high speed camera and the spotlights used for filming the drops are used for the Doris Drop Test System as well. These are not regarded as a part of the Doris Drop Test System and have not been altered. All parts are described specifically in the sections below.

3.1 Hardware

The robot controller is the central operating device that controls both the robot and the lifting column. It also keeps track of when it is allowed to open the safety doors to the safety cage. The robot controller software waits for instructions to be set by the Doris Management Software installed on a Windows based PC. The robot controller then sets the robot unit and the lifting column into the right positions to perform drop tests.
Fig. 1 shows the Doris Drop Test System. Mobile phones are placed in the fixtures in front of the robot before they are lifted by the robot and dropped above a certain impact point.

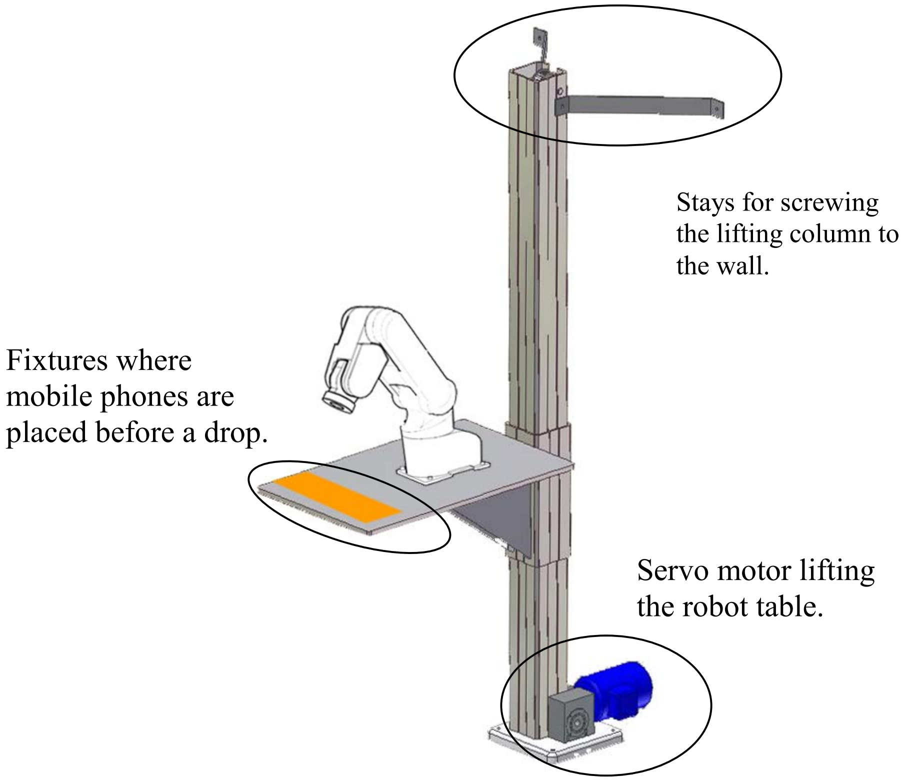

Fig 1. Hardware equipment.

3.1.1 Robot

A central component of the hardware equipment is the robot unit. The robot used in the Doris Drop Test System has 5 axes, with a precision of ±0.02 mm, a speed of 2,100 mm/s and a handling payload of up to 2 kg, and is therefore perfect for testing and accurate material handling. The robot has AC servo motors on all axes with their own absolute position encoders. The robot's high speed controller is very powerful and can handle multitasking, Ethernet links and up to 12 additional axes, in this case the lifting column.
The robot is fixed upon the table of the lifting column which is connected to the robot as an extension axis. Therefore it is integrated in the robot coordinate system and is controlled by the robot controller just as any of the robot axes to lift the robot tool centre point to the right drop position.

3.1.2 Pneumatic Gripper

The pneumatic gripper is attached to the robot flange and is used for gripping the mobile phones. It is equipped with exchangeable plastic extensions that are custom made to fit one specific type of mobile phone model. The plastic extensions are made to have four different points of grip, by the top-bottom sides and by the left-right sides of a cuboid shaped device. A magnet valve directing the compressed air positioned in the back of the robot below the J1 axis, is manoeuvred by the robot controller. The pneumatic gripper is shown in Fig. 2. Fig. 2a shows the gripper in its closed position whereas Fig. 2b shows the gripper in its opened position.

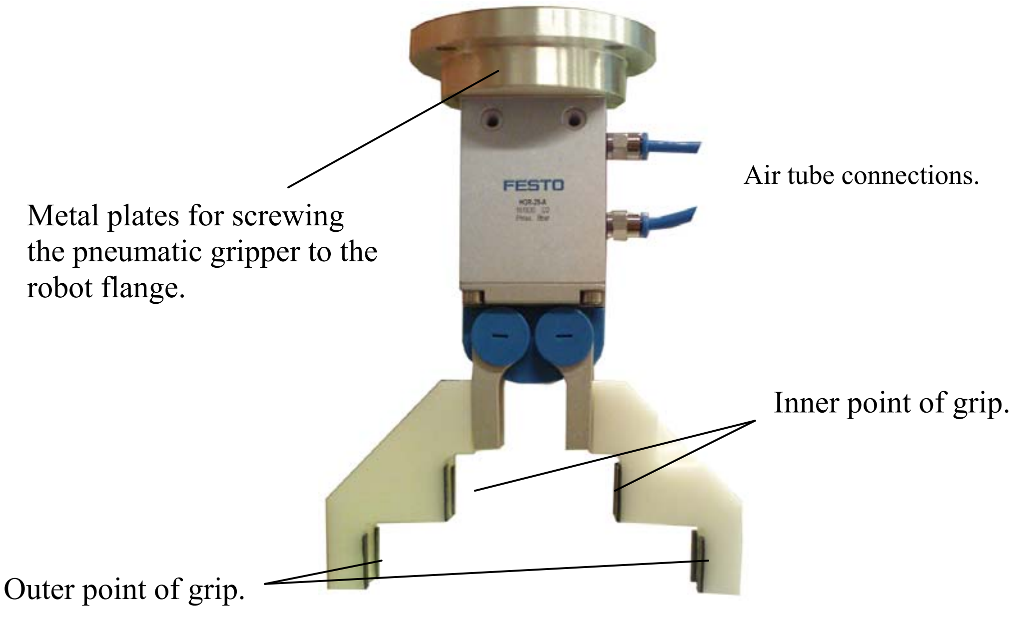

Fig 2a. Pneumatic gripper in its closed position.

Fig. 2b. Pneumatic gripper in its opened position.

3.1.3 Robot Controller

The robot controller controls the robot movement. The controller has its own memory, keeps track of the absolute position of every axis, and translates position coordinates to absolute positions for every movable axis connected to it. The robot controller also stores robot programs in the memory, ready to be executed at any time.
The robot controller is a 64-bit RISC processor. It supports genuine multitasking, up to 32 tasks simultaneously, and has an optional Ethernet link. Hence, it can control other system components at the same time as performing its own tasks. It can control up to 12 axes. It also has a connection port for COM communication.
The programming language for the robot controller is a modified variant of BASIC suitable for programming robot movement applications.

3.1.4 Lifting column

The lifting column is integrated with the robot controller and works as an external axis to the robot system. It is referred to as L1 in the coordinate system or as the 7th axis. The lifting column is used for setting the device for testing to its proper height before it is dropped. The lifting column is programmed to automatically move to the right position when drop testing mobile phones. There is no need for additional manual adjustments of the lifting column.

Fig. 3 shows the construction that consists of a vertical quadratic tube (the column) with a motor in the bottom that drives a chain. The chain is connected to a sled with an iron table where the robot is fixed upon (refer Fig. 1). The lifting column is perfect vertically fixed with bolts to the floor and stays to the wall. The stays (refer Fig. 1) together with metal plates in the bottom of the lifting column (refer Fig. 8) work as mechanical stops preventing the sled to reach out of bounds.

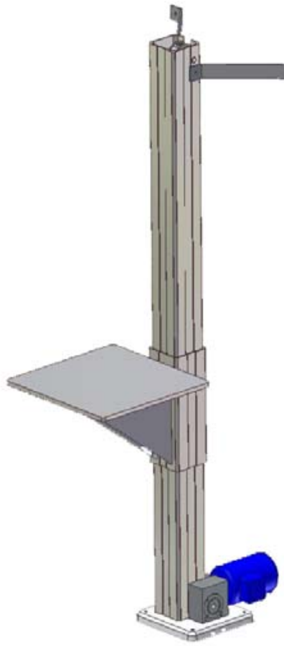

Fig 3. Lifting column.

3.1.5 Pick Position Fixtures

The robot uses two different pick positions, A and B, from where it picks up devices for testing. The reason for two pick positions is described in the Section 5.1.2. The pneumatic gripper grips the devices orthogonally over the rear or front side.

- Pick position A - The device for testing should be placed face up with its top side towards the robot.
- Pick position B - The device for testing should be placed face down with its top side towards the robot.

As with the gripper extensions the fixtures are custom made for fitting a mobile phone model by its dimensions. By using custom made fixtures the robot is guaranteed to pick up the devices by the exact same point of grip and perfect perpendicular to the mobile phone regardless of who is performing the drop tests. This, together with the robots' high precision, is a key requirement and one of the greatest advantages of the Doris Drop Test System, enabling anyone at anytime to perform time effective, accurate, and repetitive drop tests.
Fig. 4 shows the two fixtures that are screwed to a metal plate. The whole metal plate is exchanged when shifting fixtures. As the entire metal plate is exchanged the Sony Ericsson personnel do not have to alter a plate by screwing the right fixture pieces together more than once.

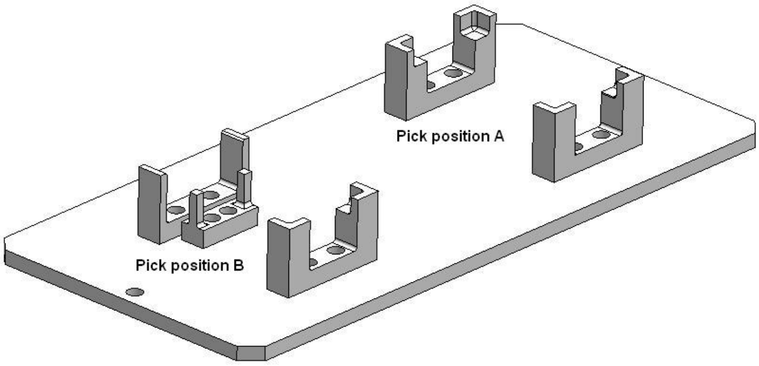

Fig 4. Fixtures where the mobile phone is placed before a drop.

3.2 Software

This section gives a summarized description of the two softwares, the Doris Management Software and the DROP Software, used by the Doris Drop Test System. A more complete description of the softwares is made in Chapter 5.

3.2.1 Doris Management Software

The Doris Management Software is installed on a PC with the Windows operating system. It is mainly used for managing projects, altering and saving drop positions and creating drop scenarios in accordance with the Test Plan. Fig. 5 and Fig. 6 show the graphical user interface for the main parts of Doris Management Software. Fig. 5 shows the main graphical user interface where scenarios and separate drops are trimmed and chosen. Fig. 6 shows the drop control where the user is instructed of how to place mobile phones for every drop.

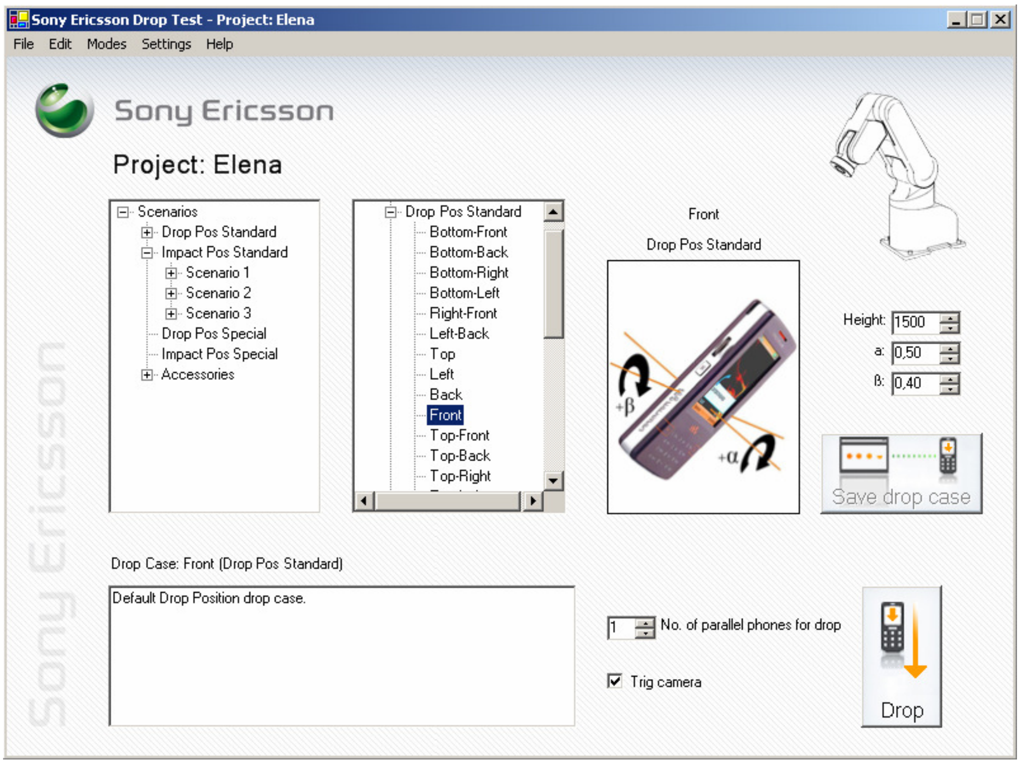

Fig. 5: Doris Management Software graphical user interface.

The main graphical interface displays all scenarios and drop cases and enables the user to select any of these from the tree lists. Trimming a drop is done in the α and β graphical components to the right. α and β answers to A and B robot coordinate components, see Section 5.1.3.

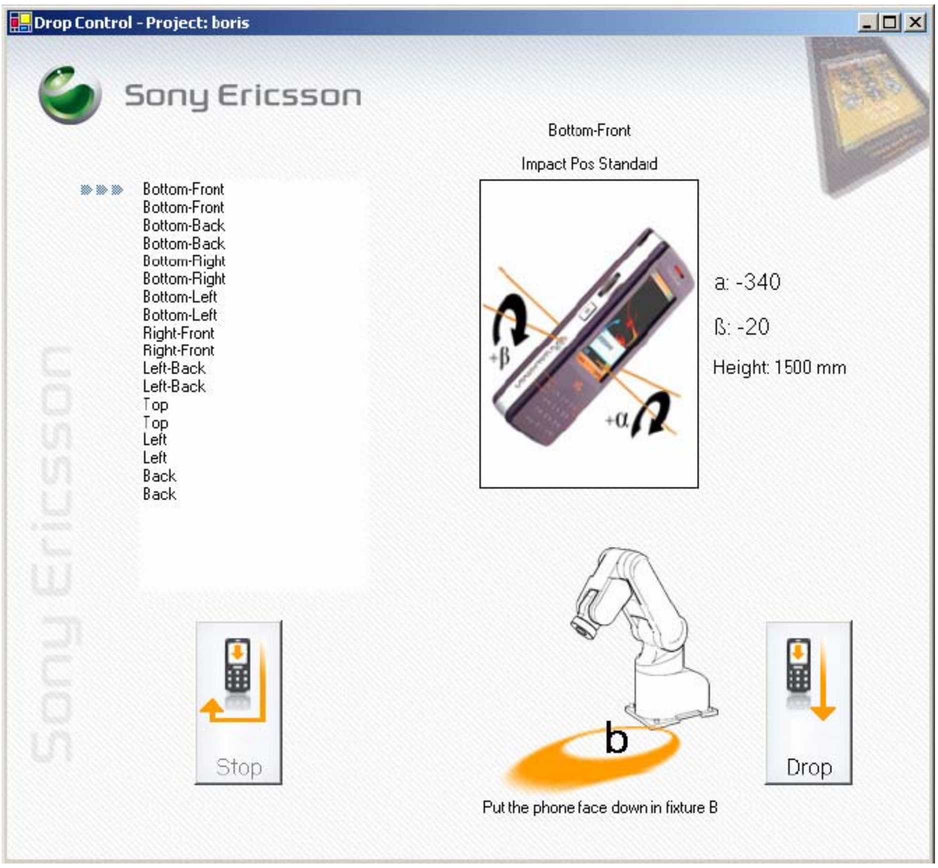

Fig. 6: Picture of the Drop Control of Doris Management Software.

The Drop Control guides the user executing drops. The current drop case is highlighted in the list of drop cases. After a performed drop, the drop case is removed from the list and the next drop case in the list is highlighted. For the example in Fig. 6, Bottom-Front is executed. The details of the current drop case are shown to the right. Most importantly the user is informed where and how to place the mobile phone before pressing the Drop button.

3.2.2 DROP Software

The DROP Software is installed on the robot controller and must be started before executing drops. The Doris Management Software calls the DROP Software to command the robot and the lifting column to pick up a device for testing from one of the fixtures, and drop it from the right position. The Doris Management Software sends all the necessary parameters of a specific drop test to the robot controller where they are saved as global variables. The DROP Software reads the stored drop data and performs the desired drop.

4 Related Work

The related work is divided into four subsections; Related Drop Test Equipment, Simulations, Mechanical Shock, and Theoretical Studies.

4.1 Related Drop Test Equipment

Studies made by Sony Ericsson's mechanical team before this thesis work resulted in specific requirements for the mechanical equipment. As mentioned in the delimitation section, one of the core requirements for this master thesis was the mechanic free fall drop principle, which would be achieved using a robot with a pneumatic gripping tool, managed by a computer software. Due to Sony Ericsson's requirements, the strict time frame for the project and the fact that studying the best suited dropping principle were out of the scope for this thesis, limited amounts of work were put on studying different types of mechanics. Confirming the adequacy of the proposed mechanical equipment was however within the scope of the project. The following mechanical equipments were studied.

4.1.1 Old Drop Test Equipment

Many drop test machines follow the same principle as the old drop test equipment used by Sony Ericsson. They use a horizontal platform that can be rapidly pulled down. Commercial machines of this kind are mainly used for drop testing larger devices or packages where the accuracy of the drops is of less importance. Even though Sony Ericsson already had discussed enhancements of the old drop test machine and abandoned the idea, this area was covered within the project, foremost to understand the difficulties of precision drops and to avoid mistakes.

The drawbacks of the old drop test equipment are thoroughly regarded in Section 2.3 and result in repeatability, precision and time cost. Enhancements regarding different fixtures would simplify the balancing of the mobile phone. Although, this idea would require many different fixtures and switching between them would be very time consuming not to mention the precision it has to be done with.

Another drawback of the old drop test equipment (and commercial drop test machines as well) is the turbulence that the rapidly pulled down platform generates.. Studies with exact measurements of the turbulence effect on mobile phones have not been found but years of drop tests clearly show that the turbulence has a negative impact of the drop precision. Even though the platform of the old drop test machine is fairly small some level of turbulence is clearly evident.

Finally, the main reason for abandoning the old drop test type of machine is that it does not offer any ways of saving the exact setup or configuration for drops. Different test team members performing drop tests within the development time of months will never be able to reproduce the exact drop using the old type of drop test machine.

4.1.2 Research Drop Tester

Liu, Wang, Ma, Gan and Zhang used a different mechanical drop test machine which can be found depicted in their technical article *Drop Test and Simulation of Portable*

Electronic Devices [4]. It uses the constrained dropping principle that offers a high level of repeatability. An accelerometer and a ground plate are used for measurements of the impact forces.
The mobile phone is hung up using cords. The movable sample holder runs freely along cord rails and is released electromagnetically, hence removing any disturbances during the release moment. Altering the lengths of the cords would imply different drop positions.
This drop machine offers a high level of repeatability but lacks the time efficiency. Even though the sample holders could be exchanged enabling reusing the cords, it would require lots of time to attach the mobile phone accurately to the cords and exchanging the sample holders between every type of drop. Hence, this drop machine was discarded relatively fast.

4.1.3 Commercial Drop Test Machines

Many commercial machines use a combination of the two previously mentioned drop principles to minimize the angular velocity of a dropped device upon impact. Sample holders that run along some rail but adjustable fixtures instead of cords onto which devices are placed upon. The sample holders can be accelerated in any speed (even though the natural gravity constant $g = 9.82\ m/s^2$ is optimal for these applications) and the fixtures release the device just above the impact point. This principle minimizes the device rotation during the free fall but achieves the same impact speed.

The machine Portable Device Drop Tester Model KD-208[5] from King Design was demonstrated to Sony Ericsson Test Team. Even though the adjustable fixtures can be custom made to fit any kind of mobile phone they have to be easily adjustable for different drop positions and easily exchanged for different mobile phone dimensions as several different mobile phone development processes can run in parallel. It was considered that none of the commercial machines could match the flexibility of the Doris Drop Test principle.

AD160A AccuDrop™ Drop Tester[6] made by L.A.B Equipment Inc. uses the same principle as the one King Design is producing but is intended for drop testing larger objects like packages etc. Like the King Design drop tester it does not have the same precision and repeatability as Doris Drop Test System, mainly because the objects are manually placed before a drop test.

4.1.4 Drop Test Machine in Alsace, France

Sony Ericsson has a partnership with Panasonic in Alsace, France, who are performing precision drop tests for Sony Ericsson. The machine used in Alsace is a robot with a pneumatic gripper that picks up devices from a fixture and drops them over a certain surface. This dropping principle and mechanical equipment has constituted the guide lines and the main idea for the Doris Drop Test System which was initially drafted by the

---

[4] S. Liu, X. Wang, B. Ma, Z. Gan and H. Zhang, *Drop Test and Simulation of Portable Electronic Devices,* Department of Mechanical Engineering, Wayne State University, Detroit, Michigan, USA, *p. 2*
[5] King Design, retrieved 7 January 2009, http://www.kdi.tw/detail/191557/191557.html
[6] LAB Equipment Inc. Specification, *AD160A AccuDrop™ Drop Tester*

Sony Ericsson Test Department and implemented within this master thesis project. The Alsace Drop Test System is a product used for the commercial services of performing precision drop tests and is therefore confidential. Only photographs were available for studies, and due to the confidentiality these and will not be presented in this document.
The Doris Drop Test System is founded on the same types of mechanics for performing the fall drop principle as the Alsace Drop Test System. Naturally there are some differences between the systems. According to the test team in Alsace configuring the system for a specific mobile phone model takes two days and requires two mobile phones. It is unknown how the configuration is entered into the system. Neither is it known if and how the drop configuration can be saved for later use.
Details about how the Alsace Drop Test System is managed are not known. According to Sony Ericsson personnel it is certainly not by a computer software with a graphical user interface. Neither is it known how the robot reaches all drop positions and heights or if it is fixed to a height adjustable platform.

4.2 Simulations

Simulation of drop tests is a growing area mostly due to decreasing financial expenses. These expenses comprise of course the production cost for a physical device that is dropped but also the shipment of devices as well as the possibility of instantly making minor mechanical or physical changes to the product within the simulation program. Drop simulations also have some disadvantages though. Perfect simulations require the computation of a tremendous amount of vertex points, every point with a specific equation for its dimensions, material and the effect from other points during the simulated impact. The complexity of a mobile phone makes simulated drops rather time consuming and less profitable than physical drop tests. The comparison between drop tests and simulations by Liu, Wang, Ma, Gan and Zhang[7], shows the differences between the two approaches, concluding that the physical drop test provides the most powerful tool to design portable electronic devices. Additionally, a simulated drop does not offer a broken physical device to examine.

Sony Ericsson has a team within the mechanical department responsible for drop simulations and research of different materials. The drop simulations made by Sony Ericsson is performed during 2-4 days depending on the drop, the amount of vertex points considered etc. Since every vertex point has to be entered into the program and the computation normally takes between 30-40 hours, simulating 26 drops would be extremely expensive and time consuming without the possibility of examining the dropped mobile phone. Studying the physical characteristics of different materials used in mobile phones lowers the complexity of the simulations and is more profitable.

4.3 Mechanical Shock

A mechanical or physical shock is a sudden and short burst of sound waves which could simulate a physical drop and impact of a mobile phone.

---

[7] S. Liu, X. Wang, B. Ma, Z. Gan and H. Zhang, *Drop Test and Simulation of Portable Electronic Devices,* Department of Mechanical Engineering, Wayne State University, Detroit, Michigan, p. 2.

The Shock Apparatus that was briefly studied needs fixtures or tooling to attach the, in our case, mobile phones to it. It would still require lots of studies and work in order to isolate the shock to a specific sector of the mobile phone (if even possible), since the Test Plan specifically requires mobile phones to be dropped in different orientations. Hence, it is very hard to recreate the free fall drop tests that Sony Ericsson requires by shock pulses. Additionally, Pitarresi, Roggeman and Chaparala among others regard drop testing to be better suited for mobile phones, personal digital assistants (PDAs) etc. considering their use[8].

The idea of applying a mechanical shock by short bursts of sound waves to the mobile phones was briefly discussed and shortly thereafter abandoned. The mechanical shock on the mobile phone is caused by the impact after a drop. To recreate that same mechanical shock by means of sound waves requires detailed studies within the specific area and the commercial equipment that is available, called Shock Apparatus[9]. This tool however is more suitable for electronic components, PCBs, and microcircuits.

4.4 Theoretical Studies

Few helpful theoretical observations were found mostly because our extraordinary goals for the thesis – perform drops accurately and repeatedly without studying dropped devices functional status afterwards. Research has been made regarding the rotation of a body during a free fall, different materials that offer high friction but low elasticity and without being sticky (for the gripping surface), but the very little amount of material found was not suitable to be implemented in this project. Lots of technical discussions with Sony Ericsson's test team and mechanical department went on during the whole project, positively influencing the development and the end result.

---

[8] J. Pitarresi, B. Roggeman, S. Chaparala, *Mechanical Shock Testing and Modeling of PC Motherboards*, Department of Mechanical Engineering, Binghamton University, Binghamton, New York, p. 1.
[9] Silicon Cert Ltd, *Reliability Newsletter, Issue No. 3 – (8/7/02 – Mechanical Shock Testing),* retrieved 6 July 2008, < http://www.siliconcert.com/reliability_news/r_news_three.htm>

5 Developing the Doris Drop Test System

This chapter thoroughly describes the development process of both hardware and software for Doris Drop Test System. One of the objectives for the project was to find a suitable equipment that had the capacity to achieve our goals; precision, repeatability and time efficiency. Thus, the intention as previous mentioned, was not to compute, measure or compare mechanical equipment parts in order to find the theoretically optimal solution.

The studies of the different hardware components were made in parallel, thus no decisions were made on which equipment to purchase before a complete awareness of the whole system was made.

5.1 Conclusion of Selections

This section is a conclusion of the entire chapter and the selections that were made.

5.1.1 Hardware Selections

- Since a complete drop scheme was completed for the 5-axis robot further studies followed. The precision of ±0.2 mm, lifting capacity of 2000 grams, the speed of 2100 mm/second and the weight of 17 kg seemed to be enough for our application. Additionally the robot system consists of a robot controller with external safety connectors and external emergency stop button providing all the tools to connect the safety equipment in order to meet all the safety requirements.

- According to tests the pneumatic gripper is fast enough to be able to drop devices without interfering with their drop path. This is essential for the performance of precision drops.

- The safety equipment and the safety cage make the system to meet all the safety requirements posed by the Swedish Work Environment Authority.

- The lifting column is equipped with a sufficiently strong motor that can handle pay loads of over 100 kg hence being able to control the robot.

- The robot system also has in- and outputs from where the high speed camera can be triggered.

5.1.2 Software Selections

- Meeting the goals for the software part of the project, VB.Net was chosen for programming the management software, foremost for its extended class library, built in common Windows graphical components and its focus towards the Microsoft platforms which is mainly used by Sony Ericsson.

5.2 Study of the Robot System

Before the robot system is studied, the idea of how the goals should be achieved must be clear. The necessary considerations to be taken into account are divided as follows:

- Reaching all drop positions
- Precision
- Lifting capacity
- Weight of robot (due to the lifting capacity of the lifting column)
- Possibilities of integration with a PC using the Windows platform
- Safety
- Pneumatic gripper – the gripper is considered a robot tool and is covered in this section

The robot that Sony Ericsson personnel intended to purchase before project start was a 6-axis robot. Since the objective of the project was to meet the goals resolving the problems described in earlier sections, any robot that had the capacity to reach all requirements would be sufficient. The robot system consists of the robot unit, a robot controller and peripheral devices such as input and output connection rails, motor cables etc. Additionally, integrating a lifting column with the robot system (described in section 5.4) requires a servo amplifier and supplementary electrical components.

5.2.1 Reaching All Drop Positions

Despite the complexity of simulating movement of all the robot arms and their range the drop schemes was sorted out before the robot was purchased. As mentioned above, two different robots could potentially handle a drop scheme, the 5-axis robot and the 6-axis robot. Since a complete drop scheme for the 5-axis robot was found the 6-axis robot was considered as a second hand choice if the 5-axis robot should fail on later studies. Therefore, drop schemes for the 6-axis robot were disregarded even though Sony Ericsson's pre-studies recommended the 6-axis robot.

5.2.2 Drop Scheme

Let us first introduce the fundamental physical appearance of a mobile phone addressed in this thesis. As already mentioned the mobile phone can be approximated to a cuboid shape. Since it is assumed to have a screen and buttons on its front side, Sony Ericsson test personnel have advised against gripping that surface. Hence, using a pneumatic griper that has two grip extensions the mobile phone has to be picked up in four different ways. There are two pick places when the phone is facing downwards and two when the phone is facing upwards. The different pick places are illustrated in Fig. 7. As can be seen in Fig. 7, the A and B pick places are not in the middle of the mobile phone but around the centre of gravity of the mobile phone. The relatively heavy battery and LCD display are the primary components affecting the centre of gravity. Being able to choose pick places according to the centre of gravity is in line with the prerequisites.
All the pick positions are manually adjusted and entered into the Doris Management Software during creation of a project. This functionality is important due to the centre of gravity might differ for different mobile phone models. Although the most important use

for this functionality is not being bound to any specific dimensions when designing fixtures for the mobile phones.
The pneumatic gripper should be fixed to the robot and it grips the phones perpendicularly. This means that when the robot is pointing the pneumatic gripper vertically downwards the drops Front and Back are performed depending on if the phone is facing downwards or upwards when gripping it. When the robot is pointing the pneumatic gripper horizontally the drops Bottom, Bottom-Left, Left, Top-Left, Top, Top-Right, Right and Bottom-Right are attained, all depending on the angle of J6-axis. The rest of the drops are achieved when the robot is pointing -45 degrees inclined downwards. Depending on the J6 angle the drops Bottom-Front, Bottom-Front-Right, Left-Front, Left-Front-Top, Top-Front, Top-Front-Right, Right-Front and Bottom-Front-Right drops are attained, assuming that the phone is picked up facing downwards. This makes all the edges and corners around the front surface of the phone. Assuming that the phone is facing upwards when gripping it, the rest of the drops are reached. This includes the drops Bottom-Back, Bottom-Back-Right, Left-Back, Top-Back-Left, Top-Back, Top-Back-Right, Right-Back and Bottom-Back-Right, consequently all the edges and corners around the back surface of the phone.

Fig 7. The four pick places.

5.2.3 Robot Position Coordinates

This section gives a detailed description of the robot position coordinates and how they are changed during trimming of a drop case. The robot position coordinates for the 5-axis robot consists of six factors, P1 = (X, Y, Z, A, B, C, L1), where X, Y, and Z are the 3-Dimensional room coordinates in relation to an orthogonal coordinate system with its origin in the centre of the robot (Z is the height coordinate). A is equal to the angle of J6-Axis. B is equal to the sum of the angles in joints J2, J3 and J5 and is necessary for specifying how a certain robot position is reached. C = 0 and is not used since it is a 5-axis robot (the same robot controller can be used for a 6-axis robot). L1 controls the first linear extension axis which will be covered in later sections. When the robot is ordered to a certain position coordinate it means that the tool centre point (TCP) is set to that X, Y, Z position, while the A and B parameters specify how the position should be reached counting axis angles relative to each other. The initial TCP is in the middle of the tip of the robot. However, the tool centre point can easily be redefined by altering the TCP property of the robot controller. For explanatory purposes the A, B and Z part of the robot position coordinates are described first.

A is equal to the angle in joint J6, hence A is used when a device is rotated around its own central axis perpendicular through the middle of the grip and through the front surface of the device.

B is equal to the sum of the angles in joints J2, J3 and J5. When the robot is pointing vertically downwards, B = 180 degrees. Consequently when the robot is pointing horizontally, B = 90 degrees. As a reference, the sum of the joint angles is 0 degrees when the robot is pointing straight upwards, but this B-value is not used since it would mean that a device would be dropped straight above the robot. In the description of the drop scheme above, the first case is when B = 180 degrees, the second case when B = 90 degrees and the last case when the robot is pointing -45 degrees inclined downwards. In this case B = 135 degrees.

The aim is to keep X- and Y-coordinates at a constant value since the devices should be dropped above the same point on the ground. Although, the X and Y coordinates naturally changes when pointing the tip of the robot differently, in order to achieve all the drop positions. Thus, the X and Y coordinates have to be chosen wisely because they must lie within the robot range for different values of B, but also be able to work for different dimensions of pneumatic grippers. To choose the suitable X and Y coordinates though the following considerations have to be taken into account:
The inner point of grip of the pneumatic gripper is at a distance of 140 mm from the tip of the robot. The outer point of grip is at a distance of 160 mm from the tip of the robot. By knowing how a device is gripped the TCP property can be set at run time. Thus it is possible to command the robot to set its new TCP at the desired room coordinate that lies within the boundaries for X and Y coordinates.
Another important aspect to consider is the height of the robot position coordinates - the Z factor. Since Z changes due to changed B values compensations must be done for different drop cases. Although this is out of range for the robot since devices still has to be dropped over the same X and Y coordinates. For this reason the lifting column is used. The lifting column has a precision of ±0.5 mm and can well compensate the Z value for different B values.

5.2.4 Precision

After establishing the drop scheme the robot's ability to reach all desired drop cases is proved. By slightly altering A and B values the drop position can be trimmed as well. Achieving Impact Position drop cases is dependent on trimming the drop positions accurately. The 5-axis robot is small, does not handle large weights and has a precision of ±0.02 mm. Comparing the precision of the fixtures, 0.02 mm is a relatively small error.

Comparing with the precision of the old drop test equipment ±0.02 is a huge improvement. Additionally, ±0.02 mm is the highest precision for a robot that moves in three dimensions, thereby leaving us with less of a choice.

5.2.5 Lifting Capacity

The lifting capacity of the robot is up to 2,000 grams although the nominal payload is 500 grams. This means that the robot can handle payloads of up to 2000 grams but not at its full speed at the margin of its range. 500 grams though can be moved at its full speed of 2,100 mm/second and at the margin of its range.
It is believed that Sony Ericsson's phones will never exceed 250 grams which makes the robots lifting capacity fully satisfactory. But as the robot also has to carry the pneumatic gripper, the metal plate used for fixing the gripper (See Fig. 2) and the gripper extensions further calculations have to be made. The pneumatic gripper with its extensions, metal plate and safety receiver weighs 325 grams. Lifting a phone weighing its full 250 grams will cause the robot to handle a total pay load of 575 grams. But as the drop scheme neither includes drops at the robot's range margins nor forces it to work at its full speed, 575 grams is fully acceptable. According to the robot specialists working for the retailer even 1500 grams would be ok with the existing drop scheme.

5.2.6 Robot Weight

The robot weight also has to be considered since it will be placed upon the lifting column. However the lifting capacity of the lifting column depends on the power of its motor. The robot weighs approximately 17 kg and the moving parts of the lifting column another 15 kg. Together with the robot retailers the goal for the lifting capacity of the motor was set to the double weight, 70 kg, in order to maintain desired precision, speed and control. This goal and the necessary calculations deciding on which motor to use were made together with the robot specialists and the lifting column specialists, since they both have experience in building robot applications. Both parties recommended motors that have the capacity of more than 100 kg, thus having no problem to lift the robot with maximum payload.

5.2.7 Integrating the Robot with a PC

One of the key prerequisites is that a software installed on a PC should be used to manage the robot system. Programming the software is a part of the project, hence the robot's interface is very important to consider before purchasing the robot. Also this was discussed comprehensively with the robot specialists. The robot system can be connected to a PC by either the COM port or by Ethernet communication using an ordinary TP-cable. Both of the connection types are very common and well documented.
Another concern is the type of information that has to be passed from the software to the robot system. How and by what is the robot system commanded? Also this matter was discussed extensively with the robot specialists. The robot system can be commanded by passing text strings. The robot system's set of instructions is wide ranging and covers more than all commands that are used for this application.

5.2.8 Safety

As the safety for the entire system will be covered in depth in Section 5.5, the robot safety is only briefly mentioned here. Two separate safety details were considered; collision detection and the possibilities of connecting peripheral safety equipment to the robot system. None of the robots in mind have collision detection. Collision detection is a feature which makes sure that the robot stops if it collides with something. Should the robot collide with a stationary object that cannot be moved without exceeding the robot's maximum force the overload alarm would go off stopping the robot. The overload alarm though goes off exceeding higher loads than the robots maximum payload of 2 kg hence posing a serious safety risk for a human.

As the robot does not have collision detection peripheral safety equipment is required. Examination of the robot system's external safety compatibility confirms that the robot controller has external slots for connection of peripheral safety equipment. The slots are for external emergency stop buttons and safety doors.

At the front of the robot controller there is an emergency stop button. Also, when an alarm is raised and the power supply to the robot system is cut, the alarm must be acknowledged before the power supply can be switched back on.

5.2.9 Conclusion

This section concludes all the necessary considerations in the study of a suitable mechanical equipment achieving the goals of this project.

The 5-axis robot is together with an adequate lifting column fully capable of reaching all drop positions through the composed drop scheme without any restrictions in trimming drop orientations. Thus it can reach all different device directions upon impact. Furthermore, its precision, weight and lifting capacity extensively covers the requirements for our application. Also the possibilities to command the robot system from a computer software using either COM or Ethernet connection, are excellent. The robot system's lack of safety details, such as collision detection, can easily be compensated for connecting peripheral safety equipment using the connection slots at the back of the robot controller.

Taking all of the considerations into account the robot system seems to be very capable of reaching the requirements and goals for the intended application.

5.3 Pneumatic Gripper

The pneumatic gripper was studied and initially tested in brief by Sony Ericsson before the thesis. However comprehensive tests had to be made understanding the entire drop test system. Although as the gripper was already purchased and approved after the tests described in the Test section, no further study and selection was made.

5.4 *Studies of the Lifting Column*

The study of the lifting column consists of the following four areas:

- precision,
- lifting capacity,
- possibility of integration of the lifting column with a PC or the robot system, and
- safety

5.4.1 Precision

The precision of the lifting column is not regarded to be as important as the robot precision since the lifting column is used only for reaching the right drop height. The minimal effect that poor precision in drop height inflicts can be disregarded. The lifting column operates as any of the robot axes, cooperating with the robot to reach all the desired drop position coordinates. Two factors are important to take into account when studying the lifting column precision; the construction and the motor. The construction has got to hold for at least the weight of the robot and all possible payloads that will be lifted. The moving parts (see Fig. 3) must run smoothly across the entire lifting column which must be built high enough to be able to reach all desired drop heights.

The retailers are constructing the lifting columns on demand, hence they are custom made. The retailers ensure that the lifting column can be built meeting all Sony Ericsson's requests. The motor of their recommendation also has a built in absolute height meter keeping track of the height regardless of power loss or other unsuspected power failure incidents. The precision is guaranteed to be ±0.5 mm. This accuracy is far less than the robot's accuracy of ±0.02 mm. The precision in height is less important though than the precision of device orientation at drop point. 0.5 mm error in height inflicts considerably less damage than 0.5 mm in device orientation. 0.5 mm out of a drop height of 1000 mm causes no significant fault in device speed upon impact or device rotation during the final ±0.5 mm fall. Device orientation faults though, are increased along the drop path as a falling device rotates.

5.4.2 Lifting Capacity

The lifting capacity is totally dependent on the motor and the chain. The lifting column constructors ensure that the lifting capacity is more than 100 kg using the motor of their recommendation, hence not having a problem lifting the robot with maximum payload. Also, the lifting column construction is built for high payloads. Furthermore the moving parts of the lifting column is moving up and down along the column, not sideways, hence detrimental vibrations are minimized.

5.4.3 Integrating the Lifting Column with the Doris Drop System

Two separate ways of integration was considered; integration directly to PC and integration with the robot controller. Both ways of integration requires that the lifting column has a connection interface.

Integration with a PC requires the lifting column's ability to be connected to either the Ethernet connection, or the COM connection since these interfaces are the most common and widely used at Sony Ericsson. Since the management software should calculate the proper drop positions it could also send height information to the lifting column.
The constructors of the lifting column were not familiar to any connection interfaces towards a PC though. Constructing our own connection interface within the frames of the project would be very expensive increasing both the amount of work and the risk factor. This type of work would also require in depth studies of both the lifting column components and implementation of drivers for Ethernet or COM ports. Hence, integrating the lifting column directly to a PC is not regarded as an option.

The second way of integrating the lifting column to the Doris Drop Test System was connecting it directly to the robot controller. This approach of course also requires some connection interface between the two. This solution though is very advantageous since both the moving parts of the system are controlled by the same entity (robot controller). Integration will also be in the field of electronics. This type of work must be done by certified electricians and can thus be run in parallel with the development. The risk of wiring errors will be minimized and the implementation of the management software will only have to consider communication with the robot system. However, a connection interface between the robot system and the lifting column still has to exist. Luckily this type of integrations is somewhat common. Industrial robots are often parts of a larger mechanical system where they are connected to conveyor belts etc. As our type of robot system supports the integration of extension axes, as described in Section 3.1.3, the robot controller can control the lifting column as an additional part of the robot itself. The robot system retailers suggested using their motor for the lifting column because a connection interface towards the robot controller already exists. Also by this solution the lifting column is totally controlled by the robot controller just as the robot itself. No explicit height meter is needed.

Integrating the lifting column with the robot system offers several advantages. The lifting column is regarded as a part of the robot and is controlled just as the robot itself. This way the management software only needs to communicate with the robot controller using the communications channel through Ethernet. Furthermore the connection is made by certified electricians, thus freeing valuable development time.

5.4.4 Safety

The safety study of the lifting column regards only how, in accordance with safety regulations, the power supply is cut upon alarm, and mechanical stops. The other safety details regarding keeping personnel from harm is covered by the peripheral safety equipment and is described in the Section 5.5 along with the rest of the safety details.
Integrated with the robot controller the lifting column is handled like any other of the robot axes. Hence, upon an alarm, the power supply is cut simultaneously for all axes, internal as well as external. The power supply to the lifting column is connected through the safety connection slots in the robot controller hence cutting the power supply upon alarm.

The mechanical stops, shown in Fig. 8, prevent the height adjustable table from sliding out of the boundaries. The mechanical stops are static metal plates placed in both the ends of the column that stops the sled when reaching them. Should the table sled collide with the mechanical stops the overload alarm is raised and the power supply is cut.

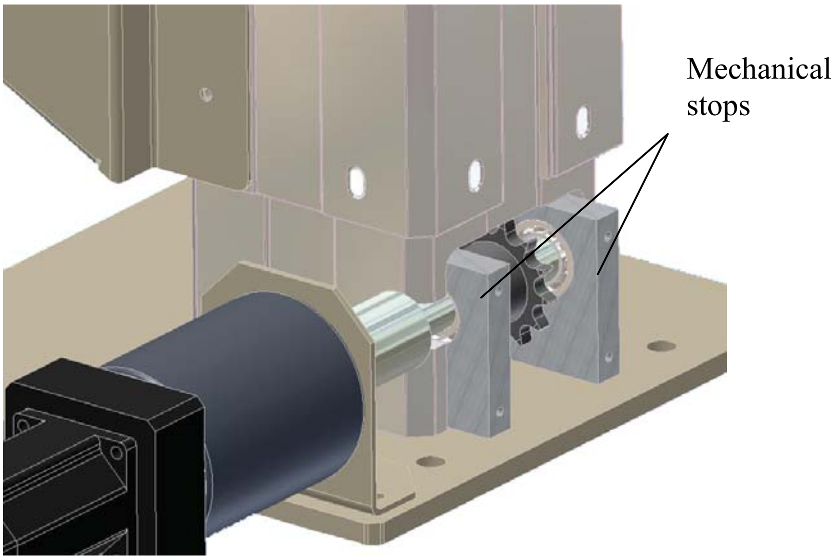

Fig. 8: Mechanical stops in the bottom of the lifting column.

5.5 Study of Safety Cage and Peripheral Safety Equipment

This section gives a thorough explanation of the safety equipment and how safety regulations are met.

5.5.1 Swedish Safety Regulations for Machines

The Swedish safety regulations for machines, below referred to as "the Regulations", in total can be found at the Swedish Work Environment Authority's homepage[10]. In this section a conclusion of the Regulations is given in order to give the reader a clarification of the constructions made.

According to the Regulations a machine is every moving entity with its own drive unit. Hence, our robot together with the lifting column is a machine. Furthermore a machine has to be encapsulated not to pose a threat to any human being, directly or indirectly. This encapsulation can be made in different ways, like for instance, a safety light barrier or a safety cage. The function of the safety light barrier is to surround the machine and if any of the light beams would be broken the power supply to the machine should be physically cut. Safety cages work in a similar way. If any of the doors (most safety cages have

[10] www.av.se

doors) to the cage is opened while the machine is running, the power supply should be physically cut.
According to the Regulations, cutting the power supply when a human being enters the machine's harms way has to be done physically. Performing a software stop or in any other way stopping the machine without cutting the physical power supply is not allowed by the Regulations. Of course, some machines have their own safety handling like collision detection, cutting the power supply whenever the machine hits an obstacle. If a machine has a certified safety handling no other measures have to be taken. But machines built up by different components are not automatically safety certified even though all the components are certified separately. Although, a machine does not have to be certified, only meet all the requirements imposed by the Regulations.
Moreover, according to the Regulations it is the owner's responsibility that every point of safety threat must be identified and dealt with.
Finally there are some details in the Regulations imposing that some equipment has to be safety certified. The only explicitly safety certified component that had to be used in the Doris Drop Test System was safety relays. Safety relays are a special kind of relays that are guaranteed not to weld into one position. The safety relays ensure the physical break of the power supply when the alarm is raised.

5.5.2 Meeting the Safety Requirements

An external firm that is and specialized on constructing safety cages and other equipment constructed the safety cage according to Sony Ericsson's specifications. Its main purpose is to encapsulate the robot system and provide the necessary safety in accordance with the Regulations. The safety cage constructors studied our use of the safety cage and used materials that are strong enough to resist our robot and that provide the essential safety.

The custom made safety cage, illustrated in Fig. 9, has two safety doors, one in front of the robot for placing the mobile phones onto the fixtures, D1, and one by the impact point for reaching and removing dropped mobile phones, D2. These doors are locked separately with a magnet lock that also can make sure that the doors are not accidentally opened. Even if the doors were to be accidentally opened when the machine is running a non contact sensor, described below, ensures that the power supply is cut.

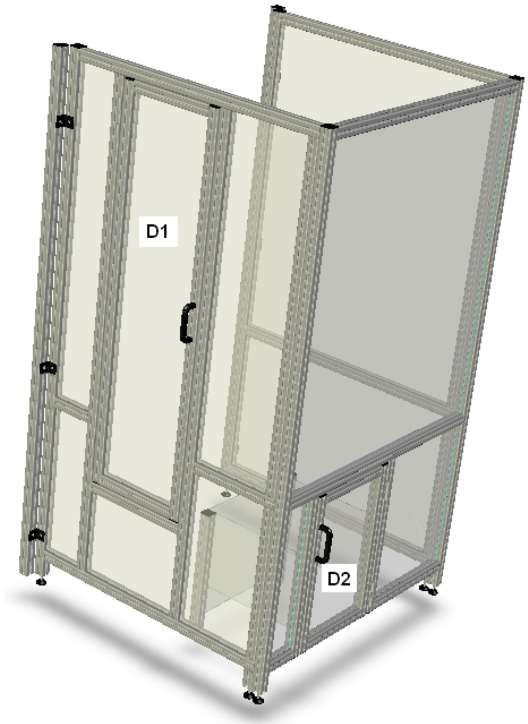

Fig. 9: Safety cage encapsulating the robot system.

The device used for keeping track of robot movement is a non contact safety sensor. The sensor consists of two units, one transmitter and one receiver. The transmitter sends a signal to the receiver which mirrors the signal back. Only the transmitter needs power supply. The transmitter is therefore placed in the stand by position for the robot. The stand by position is the robot position that it starts from and always returns to after a performed drop. The receiver is fixed to the pneumatic gripper. Should the transmitter loose sense of the receiver it means that the robot has left its stand by position. Serial connecting the safety sensors with the doors an alarm is raised only when the robot is not in its stand by position and when one of the doors is opened. When the alarm is raised the power supply is cut. As the sensor is contact free it is only secured when the two sensors are close together. In case of a sensor failure the two sensors will not be able to detect each other hence raising an alarm if any of the doors should be opened.
As the table of the lifting column runs up and down by one of the doors a human being can get squeezing injuries in its end positions. For this reason safety rail bumpers are connected to the system. One of the rails is fixed underneath the table and one is fixed underneath the door post. If one of the rails are squeezed the alarm is raised, cutting the power supply to the machine.

The safety equipment, safety cage doors, non contact safety sensor and the safety rail bumpers, is connected to the robot controller. As mentioned, the back of the robot controller has connection slots for the connection of external emergency buttons and external doors. The non contact safety sensors can be connected in serial with the doors to the external doors contact and the safety rail bumpers can be handled like emergency buttons.

5.6 Other Peripheral Devices

Other peripheral devices are the high speed camera and the extra lights. These are the same that have been used together with the old equipment. The lights are used to light up the impact position to get a good recording with the high speed camera. They are not connected in any way to the rest of the drop test equipment. The camera though should be triggered when a device is released. The camera has an external trigger that is triggered with a 24 Volt signal. The extra in- and outputs in the wiring cabinet are used for triggering the camera.
The camera is managed by its own software. This software provides an easy to use graphical user interface which the test team is used to; hence no changes have been made.

5.7 Examination and Selection of Software Parts

This section covers the choices made when constructing the Doris Management Software and the DROP Software in the robot controller.

5.7.1 Architecture of the Management Software

In order to meet all the functional requirements for the software there are several entities that have to be programmed. Fig. 10 shows an outline for the program design in a modular diagram. Every module is given a detailed description below.

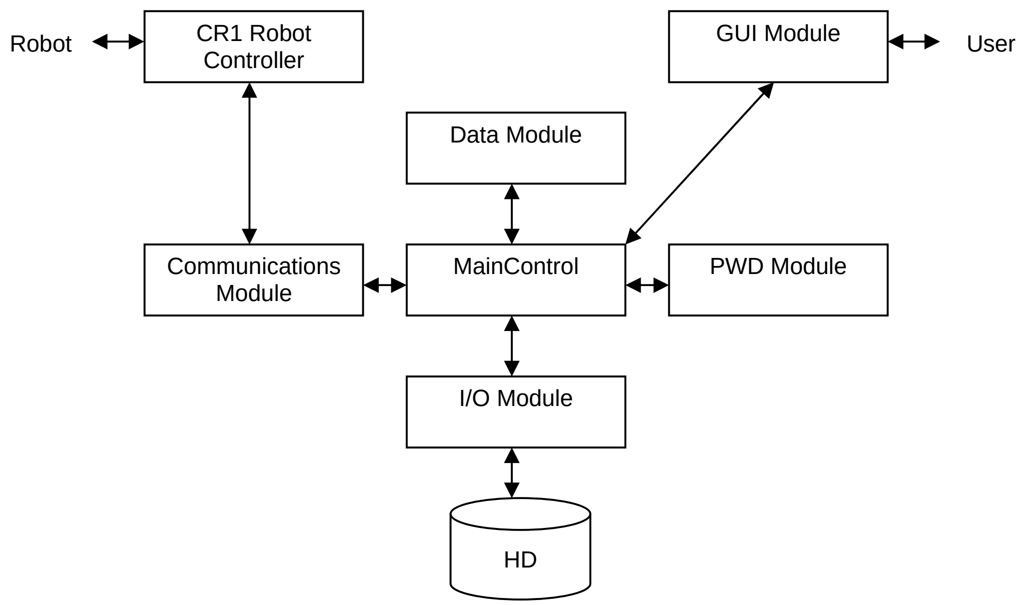

Fig. 10: Outline of program design.

MainControl Module
The MainControl is the module that keeps track of the program flow and the calculation of positions. It is through the MainControl module that all the other functions are called. The main method is in the MainControl.

Data Module
The Data module holds the entities of the program that represents the different data of the program, i.e. Projects, Scenarios and DropCases.

The most basic data entity in the management software is a DropCase. A DropCase stores details about specific drop cases. These details are coordinates for pick position and drop position, name, type, height, id etc.

The data entity Scenario is the smallest software entity - a queue that contains references to drop cases by drop case id number. The fact that scenarios only contain references to drop cases instead of containing actual drop cases is the most beneficial solution. Deleting a scenario does not affect any drop case, only a reference to it. In a similar manner, trimming a drop case affects every scenario that contains a reference to that drop case. The benefit of this solution is that the creation of a scenario does not require creating and trimming new drop cases, and deletion of a scenario does not change the list of drop cases. Hence, managing scenarios does not change the set or details of drop cases. Furthermore, the amount of data is kept low since all the information is stored only in the DropCase entity.

The largest data entity is the Project which is used to store references to DropCases and Scenarios. The Project data entity also stores other information about the environment such as the phone dimensions etc. Since this information changes between phone families it is strongly recommendable to create a new Project for every type of phone that is being drop tested, even though the phone dimensions are the same. The data entity Project is stored in files thus saving the configuration of the environment for the project, the set of scenarios and the set of drop cases associated with the project. Project files are ready to be opened at any time allowing any user at any time to reproduce a specific drop case or scenario regardless of creator or creation date – the definition of one of the main goals for the project.

Password (PWD) Module
The PWD module manages the trim users and every function that is connected to the authentication. It uses the I/O module to read and write the users list from file. The PWD module uses the GUI module through the MainControl module (see Fig. 10) to interact with a user when logging in. Finally the PWD module keeps track of the timer and the automatic log out function.

Communications Module
The Communications module is the link between the software and the robot system and is used by the MainControl to send all commands to the robot controller. It runs in a

separate thread and mainly consists of an Ethernet reader and writer that checks robot status and sends information to the robot respectively.

I/O Module
The I/O module is the link between the hard drive and the software and is used by the MainControl to communicate with the hard drive. It consists of a file reader and writer that read files such as project files and the user file, and writes to new or already existing files.

GUI Module
The GUI module is used for every interaction with the user. The GUI module is used by other parts of the management software to send or get information from the user. It also holds the windows classes that build up the main window, the drop control window, the options form and so on.

CR1 Robot Controller
The Robot Controller runs the DROP software described in Section 5.7.3.

5.7.2 Programming Language for the Management Software

The programming language VB.NET was chosen for a number of reasons. Many languages could be used to build a management software but VB.NET among a few other languages were the ones to meet all the requirements. The .NET framework was chosen mainly because the advantageous way of programming Windows applications for the Windows platform. As most of the future users of the Doris Management Software are not expected to be experienced in working with computers, common graphical Windows components are helpful to use. The .NET framework also supports the programming of common Windows components with a large class library. Also the .NET framework is installed on Sony Ericsson's computers world wide. The use of a .NET programming language is also beneficial from the aspect of maintenance as the VB.NET and C# languages are very wide spread.

The management software basically needs to have graphical components, perform simple calculations including reading and writing to the hard drive and an Ethernet connection, so both the languages C# and VB.Net would suffice.

5.7.3 Architecture of the DROP Software

The DROP Software, programmed in the proprietary robot controller language (a dialect of BASIC), is installed in the robot controller. It is the software that communicates with the Doris Management Software. The main part of the DROP software is a loop that checks for flags to be set by the management software. When a flag has been set, the DROP software enters the corresponding sub routine. Aside from the DROP routine that starts the dropping cycle, the DROP software has the other following sub routines: TOSTART, TOPPOSA, and TOPPOSB. The sub routine TOSTART moves the robot to the start position. It does not move the lifting column, mainly for time efficiency reasons. The sub routines TOPPOSA and TOPPOSB move the robot to the pick positions A and B. These positions are used when saving new pick positions to a new project.

The Dropping Cycle

After the drop flag has been set the DROP software enters the DROP routine and starts the dropping cycle. The dropping cycle consists of nine steps as follows:

1. The DROP software deactivates the opening switches to the safety doors.
2. The DROP software checks variables and other information about the drop.
3. The DROP software calculates the proper dropping coordinates.
4. The robot moves to the pick position and the lifting column moves to the right height.
5. The pneumatic gripper grips the phone.
6. The robot moves to the right drop position.
7. The pneumatic gripper releases its grip.
8. The DROP software gives a trigger signal to the camera.
9. Sub routine call to TOSTART.

The information that is received from the management software, aside from the drop flag, is a pick position, a drop position, height for the lifting column and delay time for the camera trigger.

6 Tests

Numerous different tests have been made throughout the entire development process of the Doris Drop Test System. These tests are divided into three parts, Initial Tests, Development Parallel Tests, and Final Tests. The initial tests cover the testing of the pneumatic gripper and its gripping surface. This could be done easily since these parts were purchased by Sony Ericsson before the project start.
Development parallel tests refer to the tests made in parallel with the development process. Since the development went on in parallel with ordinary activities at Sony Ericsson, the Doris Drop Test System has been tested by ordinary usage and by ordinary personnel throughout the whole development process. This opportunity of testing is rare but very valuable as it optimizes the functionality and use of the finished product.
The final tests are preparatory for the acceptance tests made by Sony Ericsson personnel. Every test case is performed minimizing the risk of acceptance test failure.

6.1 Conclusion of Test Results

The conclusion of results is divided into the three areas: precision, repeatability, and time efficiency. The following results were observed:

- The precision of the robot is very high and it is able to drop a device in any way desired by trimming each drop case. The 26 standard drop cases can be performed accurately up to 100 %.

- Doris Drop Test System has increased the repeatability from approximately 10-15% to 85-90%. The same level of repeatability is achieved regardless of by whom or when the tests are performed.

- The increase in time efficiency is very high since the device is very easily placed before a drop and there is no need for manual adjustments of the equipment. Trimming of the new drop test equipment is time consuming but offers accuracy and repeatability regardless of by whom or when tests are performed in return. Due to the fact that the Doris Drop Test System does not depend on the human error factor this approach gives better drop results and is less time consuming.

6.2 Initial Tests

6.2.1 Tests of the Pneumatic Gripper

One of the most essential parts of the drop test system was the pneumatic gripper. Not being able to drop devices in a repeatable manner could jeopardize the whole project. For this reason tests on the pneumatic gripper had to be made preceding the start of the project.
The main goal for testing the pneumatic gripper was to attain repeatability. Being able to repeat drop tests, simple redirections of the gripper would enable achieving all desired device impact directions.

As the pneumatic gripper was purchased before the actual project initialization, tests could be performed to ensure required functionality. Being able to drop devices with high accuracy, one essential factor is the pneumatic grippers release speed. The slower the gripper releases the device the more it will interfere with the devices natural drop path. So, how fast must the pneumatic gripper be? As stated in the delimitation section the object is not to find the fastest pneumatic gripper but only one that fully meets the demands on the drop test system.

Theoretical Tests

The theoretical calculations could be made very complicated and since they do not lie within the scope of the thesis they were regarded more as a guideline. Theoretically, the pneumatic gripper should be faster than the released falling device to loose all physical contact with the device before it begins to fall. According to the manufacturer the pneumatic gripper's release acceleration at 6 Bar, the pressure that Sony Ericsson's test lab holds, is higher than the gravity constant. The thorough empirical tests described below ensured that the gripper was fast enough.

There are a few more factors to consider for a successful drop test; the gripping surface and the shape and dimension of the grip extensions. The gripping surface is separately covered in Section 6.2.2. The shape and dimension of the grip extension though leads to another potential problem. Fast moving objects through air leads to turbulence which in this case can interfere with a dropped device's natural drop path. This is one of the reasons why the gripper extensions must be built small. Another reason is simply because the robot handles relatively small weights. As the pneumatic gripper with its extensions is symmetrical the turbulence is also fairly symmetrical around the device. Although turbulence interferes with the natural drop path in an uncontrollable way, the fast moving gripper extensions are symmetrical and so small that the turbulence can be left out of account. Besides, if the turbulence would be too high the practical tests of the pneumatic gripper would not be successful.

Practical Tests

The empirical tests were most important in order to determine if the pneumatic gripper is fast enough. After determining how the robot would direct the gripper during a drop, one specific drop case arose as the most critical; the case where the gripper is underneath the device during release and while gripping the device with the inner point of grip (see Fig 2). (This can be done by executing a left or right drop while gripping the phone by pick places A and B according to Fig. 7) The inner point of grip has a slower acceleration than the outer since it is closer to the center, and should therefore maximally interfere with the drop path regardless of how the gripper is directed.

The empirical tests of the pneumatic gripper were made by fixing the pneumatic gripper in this specific direction and performing Left and Right drops using three different mobile phones with the same dimensions (the gripper extensions must be exchanged for different device dimensions). The evaluation was made in two different ways; examining marks on the dropped device and by filming the impact. Both ways of evaluation showed the same result. Repeatability was obtained but the device was slightly tilted forwards at impact. By manually redirecting the gripper a few degrees we obtained repeated acceptable left and right drops. With a precision of ±0.02 mm, the robot is ideal for redirecting the gripper.

The empirical tests had one major shortcoming. The devices were placed into the pneumatic gripper manually while the robot would pick devices from fixtures, hence gripping them identically.

6.2.2 Testing Gripping Surface

Minimal interference in drops requires two specific properties of the gripping surface; high friction and zero elasticity. High friction counteracts a gripped device to slide out of its grip enabling identical drops to be performed. Although, the friction cannot be too high since the surface would then stick to the device. Any material would of course have enough friction if the grip was sufficiently tight. There were two major reasons though, as to why arbitrary grip strength could not be used. Sony Ericsson's lab only holds six Bars making it impossible to use any grip strength. Moreover, too high grip strength could cause damages to the mobile phone.
The second property, elasticity, tends to affect the device during the release moment. During release the surface straightens out but not necessarily symmetrically over the two points of grip. This causes great interference in the drop path.

Finding the best suited material for the gripping surface would be very complicated and is also out of scope for this thesis. Although, a few different materials were tested in order to find a suitable material for this application. Dilrin (plastic), different kinds of rubber, paper and sand paper were tested. The Dilrin plastic, which is the material of the gripper extensions, did not work at all since the friction was too small. The gripper could not even keep its grip of the device. Paper was a little better than Dilrin but was very unreliable in keeping its grip of a device. Of all the different kinds of rubber that was tested the best kind of rubber was the thinnest rubber film that was glued to the gripper extensions. Another problem arose though. The value of rubber friction is not static. The older the rubber film gets, the more dust it attracts, causing a decrease in friction. A brand new rubber film was so sticky that it set a device into an uncontrollable spin. Hence, using rubber as gripping surface is not suitable.

The material that gave satisfactory test results and that is currently in use is sand paper. Sand paper is not as changeable over time as rubber, it is not elastic at all but it provides better friction than plastic. Sand paper also attracts dust which decreases the materials friction but at a much slower rate than rubber. Cleaning the sand paper surface is simply done by occasionally wiping the dust off with a piece of cloth or with a finger.

6.3 Development Parallel Tests

The development of the Doris Drop Test System has been going on in parallel with ordinary work at Sony Ericsson. The system has therefore been used and tested during development not only by the developer but also by the test personnel. By having test personnel using the drop test equipment during development, the spectrum of different

tests made to the system is very wide. The development tests are very valuable since the equipment is extensively used in regular activities and in different live situations. This enables Sony Ericsson not only to report defects and errors but also minor design weaknesses. Correcting design weaknesses guarantees that the end product is optimized for Sony Ericsson drop test use.
Development tests are also very beneficial since they are performed outside the actual project timeframe and by other people, thus not acquiring any costly development time from the project.

Development tests require a special work flow where the drop test system is ready for use at certain times. The work flow resembles the Scrum-method where minor development changes are implemented always leaving a running drop test system. The progress was then reported to the test team before continuous development tests resumed.

6.4 Final Tests

The final tests are a preparation for the acceptance tests. Every specific requirement from the requirement specification is tested and the drop test equipment can be configured to perform optimally at the acceptance tests.

6.5 Acceptance Tests

The quality of the system is guaranteed by the acceptance test which is performed by the test team at Sony Ericsson. Like for the final tests, every requirement from the requirement specification is tested separately ensuring functionality as agreed upon prior to the development. Passing the acceptance tests marks the conclusion of the development process, making the system deliverable and ready for final use in regular activities.

7 Experimental Results

Comparison between the old drop test equipment and Doris Drop Test System was mainly done by an empirical examination of the three major areas of our goals.
Using strain gauges and accelerometer like Ong Y.C & Co.[11] would be a very accurate way of comparing the old with the new drop test equipment, although the focus of the project, the very tight time frame together with the lack of adequate instruments made this approach impossible. Therefore the tests were made together with two of the most experienced Sony Ericsson test team members, examining the impacts. The test team members were of course familiar with the new drop test equipment thanks to the development parallel tests.

Naturally, all drops were performed after trimming of the new drop test equipment. The time consumed for trimming is covered in the time efficiency section below.

7.1.1 Precision

The tests were made by dropping a device exactly once in every one of the 26 different drop cases using each one of the drop test equipments. The test team members performing the tests judged the results by examining the high speed film and either approving or disapproving the device's directions upon impact.

The score for the new drop test equipment was 100 % since every one of the 26 drops was successful. The score for the old drop test equipment reached ~64 %. The hardest type of drops was corner drops. The easiest drops were surface drops (front, back etc). The main reason for this result is because the mobile phone needs to be manually balanced on the old drop test equipment before a drop. The balancing arm of the old drop test equipment is not sufficient for balancing the mobile phone in any desired position which results in limited trimming possibilities.
Another disadvantage using the old drop test equipment when performing corner drops is that the mobile phone has a non symmetrical position during its fall, which causes a higher level of rotation of the mobile phone before impact. This causes even higher requirements on the precision of trimming possibilities. Surface drops, achieved by simply placing the mobile phone with its desired impact surface facing down, results in the mobile phone having a rather symmetrical position during its fall. However, trimming the drop position for symmetrical drops a few degrees is impossible using the old drop test equipment.
Using the new drop test equipment trimming is both accurate and simple. The robot holds the mobile phone in any desired position before releasing it and accurate trimming is easily achieved.

[11] Y.C ong, V.P.W. Shim, T.C Chai, C.T Lim, *Comparison of Mechanical Response of PCBs Subjected to Product-Level and Board-Level Drop Impact Tests*, National University of Singapore, Impact Mechanics Laboratory, Department of Mechanical Engineering, Singapore, p. 1.

7.1.2 Repeatability

The tests were made by testing eight different drop cases. Each drop case was made exactly five times. The Sony Ericsson test team members performing the tests judged the similarity of device direction upon impact by examining the high speed film of each of the five drops, either approving or disapproving a whole drop series. An approved drop series must get at least four out of the five drops.
Eight drop cases were included in the repeatability test; Top-Left-Front, Bottom-Right-Back, Bottom-Front-Left, Front, Left, Left-Front, Top-Back, Bottom-Right – three corner drops, two surface drops and three edge drops.

The score for the new drop test equipment totalled 87.5 % resulting in 7 out of 8 successful repeated drops. The old drop test equipment totalled 12.5 % passing 1 out of 8 repeated drops. The only passed drop with the old equipment was the Front drop case while the Left-Front drop case resulted in a failure for the new drop test equipment.
The main reason for the poor result of the old drop test equipment is because a human, regardless off experience, can never place a mobile phone exactly the same twice. Passing the Front drop case was little surprising as it is the easiest prepared drop case. The mobile phone is easily placed without the need for using the balancing arm.
No definite explanation could be given for the failed drop case using the Doris Drop Test System. Further tests particularly on the Left-Front drop case gave successful results. The most probable explanation was the risk of the mobile phone gliding slightly when gripped and moved by the robot.

7.1.3 Time Efficiency

Comparing precision and repeatability is relatively hard but still very easy next to the time efficiency comparison between the two test equipments. However, there are a few areas where time comparison can be done by logic analysis.

Placing Devices
Using the old drop test equipment, placing the device before a drop is very time consuming. In the case of front or back drops it is simple only by placing the phone onto the ramp. But placing devices before a corner drop is very hard, especially after a few drops when the phone is dented.
Using the new drop test equipment, placing devices before a drop is very easy and simple. Testers only need to put a device properly in the fixture. As mentioned in previous sections the fixture is made for each specific phone family thus fitting each phone perfectly. In addition, the management software instructs the tester of how and where to place the phone before a drop.

Adjustments of Equipment
Several pieces of adjustments have to be made when performing drop tests. Adjusting the arm for balancing devices is covered in the previous section. Adjusting drop height is also very time consuming. Using the old drop test equipment adjusting drop height includes unscrewing the height adjustable sled from the rail, moving it to the right position by measuring the height and screwing it back to the rail. The same procedure has to be made if a concrete tile of a different thickness is used for an impact zone.

Using the new drop test equipment no manual adjustments have to be done. The lifting column is integrated with the robot system and works as an external axis. Therefore the drop height is automatically adjusted for each drop. In the case of using a different concrete slab there is an options form in the management software where the thickness is entered into the program. The management software automatically calculates the proper drop height, also with regard to mobile phone drop direction, and sends the robot to the right drop height.

Trimming Efficiency
No trimming has to be done using the old drop test equipment. The success of proper drops depends on the experience of the tester.
One of the weaknesses of the new drop test equipment is that it has to be trimmed for every type of phone that is being tested. The test team must go through all the 26 drop cases and enter the proper angles of α and β that builds up the robot position coordinates. Trimming the drop test equipment for a specific phone model is done in 2 up to 12 hours depending on the experience of the tester and how accurate the drop cases have to be. However, trimming is done only once for every type of phone and enables any one (even non members of the test team), at any time to accurately perform any test during the entire phone development time. Considering this, 2 to 12 hours of trimming really is not that much of an expense.

7.1.4 Remaining Comparisons

Remaining comparisons are divided into two areas; safety and cost. Both are covered in detail in this section.

Safety
Both drop test equipments are very safe to use although the robot system has much more safety equipment connected to it. Since the construction of the old drop test equipment is fairly simple there are no objects moving by other force than gravity. According to Swedish law regarding machine safety no additional safety equipment is required when no explicit driving force is used. This is of course not the case with the new drop test system built up by a robot system.

The moving parts of the new drop test system are the robot and the lifting column. Getting stuck underneath the lifting column or between the robot arms can cause contusion or squeezing injuries. Since a part of the project was to add the safety equipment required by Swedish Safety Regulations the new drop test equipment is regarded as safe as the old one. As described in previous sections the safety equipment consists of safety rail bumpers, safety contacts detecting robot movement, and a cage with safety doors that surrounds the robot system.

Cost
The difference in cost for the two drop test systems is of course quite significant. The old drop test system was built by Sony Ericsson personnel using mostly in house material. The exact cost is unknown but is many times lower than the total cost of Doris Drop Test

System. Of course, in this case the development cost is probably higher for the old system comparing salaries with the thesis remuneration (which, by the way, I am more than satisfied with), but given a consultant company developing the drop test system the cost would be much higher for the new system simply because of the necessary development time. This expenditure though, occurs only once.

The set up cost is more interesting to compare. Disregarding the cost of the equipment, the cost for setting up the old drop test equipment is rather low. It includes screwing the equipment to the wall and adjusting the drop height. The work is done in no more than four hours.
The set up cost for the new drop test system is many times higher since there are many more pieces of equipment that has to be put together and configured. Setting up the Doris Drop Test System is covered in detail in the user manual provided with the equipment. The set up includes putting the equipment together, installing the software, setting both hardware and software variables etc. It is recommended that the set up is carried out by a robot integrator but it could be done by someone experienced using the system. The integration of the lifting column and the robot system though, should be made by an experienced electrician since the wiring is rather complex.

Maintenance cost is also important to consider. The maintenance cost of the old equipment is close to zero since it only needs lubrication and a new rubber band once every other year depending on the usage frequency. The maintenance cost for the new system is somewhat higher even though the cost includes, as for the old system, lubrication, battery changes and minor part exchange. As the robot is much more complex though, the cleansing and lubrication is more time consuming than for the old system. Luckily, Doris Drop Test System maintenance, including robot maintenance, can be done by any Sony Ericsson personnel.

Considering the equipment cost the cost for the Doris Drop Test System is, just as expected, many times higher. The exact cost of the two systems is not important for the thesis report and is therefore omitted since it is a private matter for Sony Ericsson.

7.1.5 Trusting the Results

There are several considerations to be taken in trusting the results. The major considerations are the following:

- Have the expectations of accurate and repeatable drop tests increased during the development of Doris Drop Test System? Would the tests of the old drop test equipment be approved before the new drop test equipment was developed?
- Are the Sony Ericsson test team members sufficiently experienced of the new equipment in order to carry out tests?
- Different test team members?
- Weaknesses of the tests?
- Repeatability tests also include precision.

Considering the poor precision and repeatability results of the old drop test equipment, is the superior performance of the new equipment affecting the judgement of the results? Surely it is. The old drop test equipment has been used for several years and is still in use at some Sony Ericsson test sites throughout the world. The superior performance of Doris Drop Test System intensifies the requirements for the drop test equipments. The result of the repeatability test only displays the difference in performance of the systems.

As the Sony Ericsson test team members have been using the Doris Drop Test System during the development tests and the test equipment is rather easy to use, the testers are fully capable of dropping phones. The trimming of drop cases can be time consuming though, but that part is disregarded when testing the accuracy of the drop tests.
The main difficulty of using the Doris Drop Test System is creating new projects and trimming drop cases. These parts were regarded during the time efficiency tests but gave no unique result. Experience in using the new drop test system significantly reduces the trimming and project creating time. Depending on experience and method used, trimming can be done in 2 to 12 hours.

There are many factors influencing the outcome of the tests, thus it is hard to eliminate all test weaknesses. Different members of the test team could maybe improve the results using the old drop test equipment. The repeatability tests could also be made on all 26 drop cases since certain drop cases are easier to repeat than others using the old drop test equipment. Although, the purpose of the tests were to ascertain the performance differences between the two equipments given a random member of the test team. The whole team is highly experienced in testing phones but determining who the best is is pointless. The drop cases picked out represents a good subsection of the three types of drop cases. There are 12 edges, 8 corners and 6 surfaces of a cuboid shape. Three edge and corner drops and two surface drops represents a good subsection of the whole set of drop cases even though surface drops seems to perform better. One of the major weaknesses of the old equipment is the part of balancing devices. That was a fact even long before the robot system was considered.

Does the old equipment’s poor result in precision cause a poor result in repeatability? Not necessarily. Nevertheless, some of the repeatability tests failed because an acceptable drop could not be achieved. The 26 drop cases are however the ones important to the Sony Ericsson and should not be discarded, even though the requirements of a successful drop is intensified. Additionally the Doris Drop Test Equipment has proved to meet all the requirements set by Sony Ericsson.

8 Drawbacks and Enhancement Possibilities

In this chapter the operation of Doris Drop Test System is discussed, revealing its drawbacks and giving a detailed description of how the Doris Drop Test System can be improved both in hardware and in software.

8.1 Drawbacks with the New Drop Test Equipment

The main drawbacks with Doris Drop Test System have already been covered throughout this report. This section summarizes the known drawbacks together with the observed issues after approximately one year of regular drop test work.

The limitation for the system is primarily handling payloads, handling speed, and gripping surface. The restrictions caused by robot handling payload require the mobile phones to weigh less than 300 grams depending on the handling speed. As commercial mobile phones are getting smaller the weight is hardly believed to cause any problems in the future.

The Doris Drop Test System is designed for dropping cuboid shaped mobile phones. However it has the possibility of dropping different upcoming types of mobile phones including the Clam Shell, Slide, and Jack Knife models. The only required changes to the drop test system are the gripper extensions and the fixtures. Later drops showed however that a slide mobile phone is impossible to grip and hold in the pick positions C and D (see Fig. 7) since the phone contracts. A minor change in the program code of Doris Management Software enabled only the pick positions A and B to be used for all the drop cases. This makes an unplanned restriction in robot handling scope but can of course be solved by the functionality of selecting pick positions.

All together the Doris Drop Test System has proved to be a highly valuable tool for performing mobile phone drop tests. Even though many requirements on the project had to be reconsidered all of the goals have been achieved, optimizing Sony Ericsson product range and mechanic quality.

8.2 Enhancement Possibilities

Many problems arouse during the development but were successfully solved. The goals achieved clearly shows the success of Doris Drop Test System. There are however several recommendations for changes to the Doris Drop Test System, both in software and hardware. Most of the changes listed below would be relatively easy and fast implemented and would give great benefit in versatility and flexibility. The reason why some of the changes cannot be applied within this project is because of hardware limitations.

8.3 Software

8.3.1 Selecting Pick Positions

Every drop case has one of the four different pick positions designated to it. These cannot be altered in any way. Being able to select pick positions would enable more possibilities of testing of clam shell or slide phones. Since these types of devices should be tested when opened there can be problems of gripping the phone by its top-bottom sides. For that reason it would be preferable to be able to select pick positions. Additionally, the ability to select pick positions makes the drop test system more independent of device structure as it may be uncertain to grip a device over a button, scroll wheel etc. Hence, the ability to select pick positions simply extends the range of possible drops.

8.3.2 Logging Drop Tests

At Sony Ericsson, drop tests are documented in hand written error reports and movie clips. After a drop test session the error reports are written in a word processing program before stored on the hard drive. Being able to document errors directly into the Doris Management Software would reduce the work effort, be less time consuming and decrease the risk of errors. This solution would also include reporting device id into the software, more discussed below.

Logging error reports directly into the Doris Management Software also opens a new range of possibilities. By keeping the test logs in a structured database for testing documentation, all kinds of information and statistics can be retrieved at any time. It would be possible to keep track of all the corrective actions and their effects, check statistics of margin of error etc. and compare the development costs between different types of mobile phones. This service would be highly effective and valuable since development teams would work more consistently without the risk of loosing a coworkers experience and expertise.

8.4 Hardware

8.4.1 Changing Dimensions of D1

Because of the risk of squeezing accidents the safety cage door D1 (See Fig. 9) should be made longer on the lower part. Note that the greatest risk of squeezing injuries is by the lower edge of the door where the lifting column table passes. By extending the lower part of the door the edge will be out of reach for the lifting column table, hence, making the Doris Drop Test System safer.

8.4.2 Adding Manageable Walls to the Inner Cage

Since the walls of the inner cage do not reach the ground (or the concrete tile) parts from a mobile phone, batteries, styluses etc. can be thrown further into the safety cage, making it hard to reach them. This solution was deliberately chosen because the possibilities of filming the impact point from different angles. Adding manageable walls to the inner cage would solve the problem of parts being thrown further into the safety cage but would not restrict the filming angles.

9 Conclusions

Doris Drop Test System has taken a great step in optimizing the drop test work at Sony Ericsson. Not only the positive results but also the fact that Doris Drop Test System has entirely replaced the old drop test equipment is a confirmation of that. Additionally, the Doris Drop Test System is, as this is written, even being installed at other Sony Ericsson test sites throughout the world, which is yet another proof of its high success.
Through this master thesis report, the main goals precision, repeatability, and time efficiency, have been the focus of attention. Due to the possibility of performing development parallel tests also the system usability has been guaranteed. The high level of precision and repeatability acquired with the Doris Drop Test System enables Sony Ericsson to test specific mobile phone parts by accurately repeating drop cases pushing their weaknesses to the limit.

Finally, the Doris Drop Test System has achieved and exceeded the goals set up by Sony Ericsson. As Sony Ericsson as one of the main mobile phone manufacturer are using the Doris Drop Test System on a daily basis, not only the physical quality on their entire product range is assured, but it also expands the overall mobile phone quality requirements throughout the world.